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A1 > TITLE OF THE INVENTION

VARIABLE FOCUS LENS

A2 > BACKGROUND OF THE INVENTION

A3 > (1) FIELD OF THE INVENTION

The present invention relates to the field of variable focal lenses, and more specifically to liquid lenses having a variable electrically controlled focus.

A4 > (2) DESCRIPTION OF RELATED ART

- An article of B. Berge entitled "Electrocapillarité et mouillage de films isolants par l'eau" published in 1993 in C.R. Acad. Sci. Paris, t. 317, serial II, pages 157 to 163, discloses a device comprising a drop of conductor liquid placed on a dielectric film covering a flat electrode. A voltage may be applied between the liquid conductor drop and the electrode.
- 10 This article describes a theoretical study of the wetting variation of a dielectric material with respect to a conductor liquid and shows that the wetting increases substantially in presence of an electric field caused by the voltage existing between the conductor liquid and the electrode. This phenomenon
- 15 is called electrowetting by the author.

U.S. Patent N° 5,659,330 discloses a display device using the electrowetting phenomenon to vary the shape of a drop of opaque conductor liquid placed on a dielectric. This document does not suggest the use as an optic lens.

- 20 An article of Vallet, Berge and Vovelle, "Electrowetting of water and aqueous solutions on poly(ethylene terephthalate) insulating films", published in Polymer, Vol. 37, N° 12, pages 2465 to 2470, 1996, discloses a deformation of

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a liquid conductor drop to which a voltage is applied. It is indicated that, when the applied voltage becomes too high, the surface of the drop becomes unstable, and microdroplets may be

As 5 **BRIEF SUMMARY OF THE INVENTION** ejected at the periphery of the drop. This makes prior art systems inadequate for forming variable lenses. Moreover, these systems need a transparent biasing electrode and a connection for the electrode, which makes the system difficult to manufacture or inefficient.

10 An object of the present invention is to provide a lens whose focus may vary continuously as a function of an electric control, by using the phenomenon of electrowetting.

Another object of the present invention is to provide a lens which is simple to manufacture.

15 Another object of the present invention is to provide a lens which is simple to use.

For achieving these objects, the present invention provides a variable focus lens comprising a chamber filled with a first liquid, a drop of a second liquid being disposed at rest on a region of a first surface of an insulating wall of the chamber, the first and second liquids being non miscible, of different optical indexes and of substantially same density. The first liquid is conductive and the second liquid is insulating. The lens further comprises means for applying a voltage between the conductor liquid and an electrode placed on the second surface of said wall; and centering means for maintaining the centering of the edge of the drop while the voltage is applied and for controlling the shape thereof.

20 According to an embodiment of the invention, the centering means allows a continuous maintaining of the centering of the drop and a continuous control of the shape of the edge of the drop while a varying voltage is applied by said means for applying a voltage.

30 According to an embodiment of the invention, the first surface is substantially flat, the contact region is

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circular and centered about an axis which is perpendicular to the first surface.

According to an embodiment of the invention, the centering means corresponds to a progressive thickening of the second surface of the wall of the chamber towards said axis, said electrode being applied against said second surface.

According to an embodiment of the invention, the centering means corresponds to a radial decrease of the wetting with respect to the first liquid, towards the center of said contact region with the second liquid.

According to an embodiment of the invention, the centering means corresponds to a radial gradient of the dielectric constant of said wall of the chamber at the level of said contact region with the second liquid.

According to an embodiment of the invention, the first surface is substantially flat, the contact region 15 is circular and centered about an axis perpendicular to the first surface, and the centering means comprises an electrode formed of one or several circular concentric strips insulated from each other, centered about said axis, the circular strips being supplied by distinct voltage sources of values decreasing towards said axis.

According to an embodiment of the invention, the chamber is cylindrical, the first surface is the internal surface of the chamber, the contact region with the second liquid corresponds to a cylindrical section of the chamber, the centering means is comprised of one or several cylindrical electrodes of same diameter, insulated from each other, placed side by side against the external surface of the chamber at the level of the border of said contact region, the electrodes being supplied by different voltages of values decreasing towards the center of said contact region.

According to an embodiment of the invention, the first surface is substantially flat, the contact region is rectangular and symmetric with respect to an axis perpendicular

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to the first surface and the centering means is comprised of an electrode formed of one or several rectangular concentric strips insulated from each other, symmetric with respect to said axis, the rectangular strips being supplied by distinct  
5 voltage sources of decreasing values towards said axis.

According to an embodiment of the invention, said wall is comprised of two non parallel planes and in which said region bridges said two planes.

**BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS**

The foregoing and other objects, features, aspects and advantages of the invention will become apparent from the following detailed description of embodiments, given by way of illustration and not of limitation with reference to the accompanying drawings:

Figure 1 shows a first embodiment of a variable focus lens according to the present invention;

Figure 2 shows a second embodiment of a variable focus lens according to the present invention;

Figure 3 shows a third embodiment of a variable focus lens according to the present invention;

Figure 4 shows a fourth embodiment of a variable focus lens according to the present invention;

Figure 5 shows a fifth embodiment of a variable focus lens according to the present invention; and

Figure 6 shows another embodiment of a variable focus lens according to the present invention.

**DETAILED DESCRIPTION OF THE INVENTION**

Figure 1 shows a simplified cross-section view of a variable focus liquid lens according to a first embodiment of the present invention. A drop of an insulating liquid 11 is located on the internal surface of a wall of a dielectric chamber 12 filled with a conductor liquid 13. The insulating liquid 11 and the conductor liquid 13 are both transparent, not miscible, have different optical indexes and have substantially the same density. The dielectric 12 naturally has a low wetting with respect to the conductor liquid 13. A surface treatment 14 insuring a high wetting of the wall of the dielectric chamber

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with respect to the conductor liquid 13 surrounds the contact region 15 between the insulating liquid drop 11 and the wall of chamber 12. The surface treatment 14 maintains the positioning of drop 11, preventing the insulating liquid from spreading beyond the desired contact surface. When the system is at rest, the insulating liquid drop 11 naturally takes the shape designated by reference A. "O" designates the axis which is perpendicular to the contact region 15 and passing through the center of contact region 15. At rest, the insulating liquid drop 11 is centered about axis O which constitutes the optical axis of the device. The elements of the device which are adjacent to axis O are transparent. An electrode 16, letting through light in the vicinity of axis O, is placed on the external surface of the wall of dielectric chamber 12, on which is situated the insulating liquid drop 11. An electrode 17 contacts the conductor liquid 13. Electrode 17 may be immersed in liquid 13, or be a conductor deposition achieved on an internal wall of chamber 12.

When a voltage V is established between electrodes 16 and 17, an electrical field is created which, according to the above mentioned electrowetting principle, will increase the wetting of region 15 with respect to conductor liquid 13. As a consequence, conductor liquid 13 moves and deforms the insulating liquid drop 11. A variation of the focus of the lens is thus obtained.

However, the center of the drop is likely to move with respect to axis O during the deformation. Moreover, the outline of the contact surface is likely to lose its circular character during the deformation of the drop. An aspect of the present invention is to maintain the circularity of the drop and its concentricity with respect to axis O while its shape changes by generating an electric field which decreases radially towards the center of region 15.

For avoiding this, according to an aspect of the present invention, a centering means for drop 11 is additionally

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provided. Examples of such centering means appear in the second to sixth embodiments of the invention described hereinafter.

Figure 2 shows a simplified cross-section view of a variable focus liquid lens according to a second embodiment of the present invention. Elements such as drop 11, axis O, chamber 12, conductor liquid 13, surface treatment 14, contact region 15 and electrode 17 are the same as those of the embodiment illustrated in figure 1. The positions A and B also correspond to the rest position of drop 11 and to the limit position of drop 11, respectively. In this second embodiment, the centering means comprises the generation of an electrical field which decreases radially towards the center of region 15. For this purpose, an electrode 26 is provided which has a surface which progressively departs from the surface of region 15 while approaching axis O. Such an electrode 26 may, for example, be obtained by depositing a metallic film on the lateral walls of a taper centered about axis O, achieved on the external surface of the wall of chamber 12 on which is placed drop 11. An alternative embodiment may consist in depositing a metallic film on the surface of a transparent dielectric resin drop centered about axis O, attached to the external surface of the wall of chamber 12 on which drop 11 is placed. The top of the resin drop is planed in the vicinity of axis O to let the light through.

One may increase voltage  $V$  from 0 volt to a maximum voltage which depends on the used materials. When the maximum voltage is reached, the insulating liquid drop 11 reaches a limit position (designated by reference B). When voltage  $V$  varies continuously between 0 volt and its maximum value, the insulating liquid drop 11 continuously deforms from position A to position B. It will be noted that, drop 11 being of an insulating liquid, no microdroplets are produced at its periphery when the voltage is high, in contrast to what would happen if the drop was of a conductor liquid (see the above mentioned article of Vallet, Berge and Vovelle).

Figure 3 shows a simplified cross-section view of a variable focus liquid lens according to a third embodiment of the present invention. Elements such as drop 11, axis 0, chamber 12, conductor liquid 13, surface treatment 14, contact region 15 and electrode 17 are the same as those of the embodiment described in figure 1. The positions A and B also correspond to the rest position of drop 11 and to the limit position of drop 11, respectively.

In this third embodiment, on the external surface of the wall of chamber 12 is placed a group of three circular concentric electrodes, 35, 36 and 37, insulated from each other, and having 0 as axis. A voltage may be applied between each of electrodes 35, 36 and 37 and electrode 17; exemplary voltages V1, V2 and V3 are shown, each of which may vary. The voltages are chosen at any time with decreasing values towards axis 0 so that the electric field generated by applying the voltages to electrodes 35, 36 and 37 decreases radially towards the center of region 15. When voltages V1, V2 and V3 continuously vary between 0 volt and their maximum value, the insulating liquid drop 11 deforms continuously between its rest position A and its limit position B.

According to an alternative of this third embodiment, each electrode 35, 36 and 37 may be connected by a switch, either to a same voltage source V, either to ground. For a constant voltage V, the shape of drop 11 is then varied by varying the number of electrodes to which a voltage is applied. In this case, the focus variation is discrete and not continuous. Only certain predetermined focuses can thus be obtained for the lens comprised of drop 11, but the benefit is then that the voltage control is relatively simple to implement.

Figure 4 shows a simplified cross-section view of a variable focus liquid lens according to a fourth embodiment of the present invention. Elements such as drop 11, axis 0, conductor liquid 13, surface treatment 14, contact region 15 and electrodes 16 and 17 are the same as those of the embodi-

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ment described in figure 1. The positions A and B also correspond to the rest position of drop 11 and to the limit position of drop 11, respectively.

In this fourth embodiment, the wall of the dielectric chamber 52 on which the insulating liquid drop 11 is placed, comprises a circular dielectric region 53, letting through the light about axis O. Region 53 has a low wetting with respect to conductor liquid 13 in the absence of a surface treatment 14. Region 53 has been treated in such a way that its dielectric constant varies radially and continuously towards axis O, and that the electric field generated by voltage V has a gradient which decreases radially towards axis O on the contact region 15. When voltage V is varied continuously between 0 volt and its maximum value, the insulating liquid drop 11 continuously deforms between its rest position A and its limit position B.

Figure 5 shows a simplified cross-section view of a variable focus liquid lens according to a fifth embodiment of the present invention. Elements such as drop 11, axis O, dielectric chamber 12, conductor liquid 13, contact region 15 and electrodes 16 and 17 are the same as those of the embodiment described in figure 1. The positions A and B also correspond to the rest position of drop 11 and to the limit position of drop 11, respectively.

In this fifth embodiment, the surface of the wall of dielectric chamber 12 on which the insulating liquid drop 11 is placed has been treated at different regions 14, 65, 66 and 67 such that the wetting of regions 14, 65, 66 and 67 with respect to conductor liquid 13 decreases radially towards axis O. A voltage V may be applied between electrode 16 and electrode 17. The electric field generated by voltage V increases the wetting of regions 14, 65, 66 and 67 but maintains the initial wetting gradient. When voltage V varies between 0 volt and its maximum value, the shape of the insulating liquid drop 11 continuously varies between its rest position A and its limit position B.



Figure 6 shows a simplified cross-section view of another embodiment of the present invention in which an insulating liquid 11 occupies the bottom portion of a cylindrical dielectric chamber and is covered by a conductor liquid 13. The chamber is designated by reference 12. The materials composing elements 11, 12 and 13 are the same as those of the previous embodiments.

A surface treatment 14 insuring a high wetting of the internal wall of chamber 12 with respect to the conductor liquid 13 is achieved above the contact region 15 between liquid 11 and the internal surface of chamber 12. The surface treatment 14 allows the position of liquid 11 to be maintained for avoiding this liquid from spreading beyond the contact surface. For simplifying the description only the top portion of liquid 11 will be considered and it will be called, like in the previous embodiment, "drop 11". When the system is at rest, the insulating liquid drop 11 naturally takes the shape designated by reference A. Axis O is the axis of chamber 12. At rest, the insulating liquid drop 11 is centered about axis O which constitutes the optical axis of the device. Several electrodes 75, 76, 77, 78, 79 are placed about the external wall of dielectric chamber 12 in the vicinity of contact region 15. The electrodes 75, 76, 77, 78, 79 are insulated from each other and a voltage V is established between electrode 75 and an electrode 17 contacting the conductor liquid 13. The electrodes 76, 77, 78, 79 are biased through capacitive influence when voltage V is established. At wall 12, the electric field generated by voltage V decreases according to a longitudinal gradient from electrode 75 towards electrode 79. When voltage V increases, conductor liquid 13 moves and deforms the insulating liquid drop 11. A variation of the focus of the lens is thus obtained. The above-mentioned electric field gradient insures that the drop permanently has a radial symmetry with respect to axis O. When voltage V varies between 0 volt and its maximum

value, the insulating liquid drop 11 varies continuously between its rest position A and its limit position B.

Those skilled in the art will be able to combine the features appearing in the various embodiments of the invention  
5 described above.

Moreover, the present invention may be subject to various alternatives which will appear to those skilled in the art.

The surface of the dielectric chamber 12 of figure 1  
10 may be concave or convex, in order to obtain a particular diopter value of the device at rest.

The contact region between the insulating liquid drop and the dielectric chamber may be treated for having a high wetting with respect to the insulating liquid, in order to  
15 simplify the positioning of the insulating liquid drop.

In the case of a dielectric chamber naturally having a high wetting with respect to the conductor liquid, the contact region may be achieved by a surface treatment adapted to providing it with a low wetting with respect to the conduc-  
20 tor liquid.

The surface treatment 14 may consist of depositing or sticking a film of a material having a high wetting with respect to conductor liquid 13.

Electrode 16 of figure 1 may be replaced with a con-  
25 ductor liquid in contact with the external surface of chamber 12, voltage V then being established between this conductor liquid and liquid 13.

It will be possible to realize a device including an array formed of groups of three, separately controlled, vari-  
30 able focus lenses, colored in red, green, and blue, operating, for example, in a binary mode, stopping or allowing through light originating from a unique source of white light, thus forming a luminous color screen which may be of big size and of moderate cost.

It will be possible to realize a device in which the above mentioned centering means are no longer used for maintaining drop 11 circular throughout its deformation, but in contrast for making the drop go from a rest position determined, for example, by the shape of the surface treatment 14, to an operating shape, determined, for example, by the outline of electrode 16. It is thus possible to create a variable focus cylindrical lens by using a surface treatment 14 of rectangular shape and centering electrodes 16 of rectangular outline.

It will be possible to apply the present invention to a device bridging more than one wall of chamber 12, drop 11 being placed, for example, in an angle or in a corner of chamber 12. According to this alternative, an electrode would of course be placed on the back surface of each wall in contact with drop 11, at the level of the contact region. Such an alternative would enable a variable deflection prism to be achieved.

As an example of conductor liquid 13, one may use water loaded with salts (mineral or other) or any other liquid, organic or not, which is conductive or made conductive by addition of ionic components. As an insulating liquid 11, one may use oil, an alkane or a blend of alkanes, eventually halogenated, or any other insulating liquid which is not miscible with conductor liquid 13. Chamber 12 may be comprised of a glass plate, treated with silane or covered with a thin coating of fluorinated polymer or of a sandwich of fluorinated polymer, epoxy resin, polyethylene.

Voltage V will preferably be alternating in order to avoid the accumulation of electric charges throughout material 12 from the surface on which drop 11 is placed.

In the exemplary embodiment of figure 1, drop 11 has a rest diameter of approximately 6 mm. The conductor liquid 13 and the insulating liquid of drop 11 being substantially of same density, drop 12 has a hemispheric shape. When it is at rest (position A), the edge of drop 11 is at an angle of

approximately 45° to the surface of chamber 12. In its limit position (position B), the edge of drop 11 is at an angle of approximately 90° to the surface of chamber 12. The described device, using as a conductor liquid 13 salt water of optical index 1.35 and, for the insulating liquid of drop 11, oil having an optical index of 1.45, achieves approximately 40 diopters of focus variation for an applied voltage of 250 volts and an electrical power of some mW. The frequency of the alternating voltage is in this case comprised between 50 and 10,000 Hz, its period being substantially smaller than the response time of the system which is several hundredths of a second.

The variable focus lens according to the present invention may have a size comprised between several tens of  $\mu\text{m}$  and several tens of mm, and may in particular be applied to the field of optoelectronic systems or to endoscopy.

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